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REPORT

16mm film: image steadiness in television presentation
Part 1: the measurement of unsteadiness and prediction of subjective impairment

No. 1971/28

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

16 mm FILM: IMAGE STEADINESS IN TELEVISION PRESENTATION

Part 1: The Measurement of Unsteadiness and Prediction of Subjective Impairment

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D. Maurice

Head of Research Department

D.T. Wright, Associate Member I.E.E.

(PH-76)

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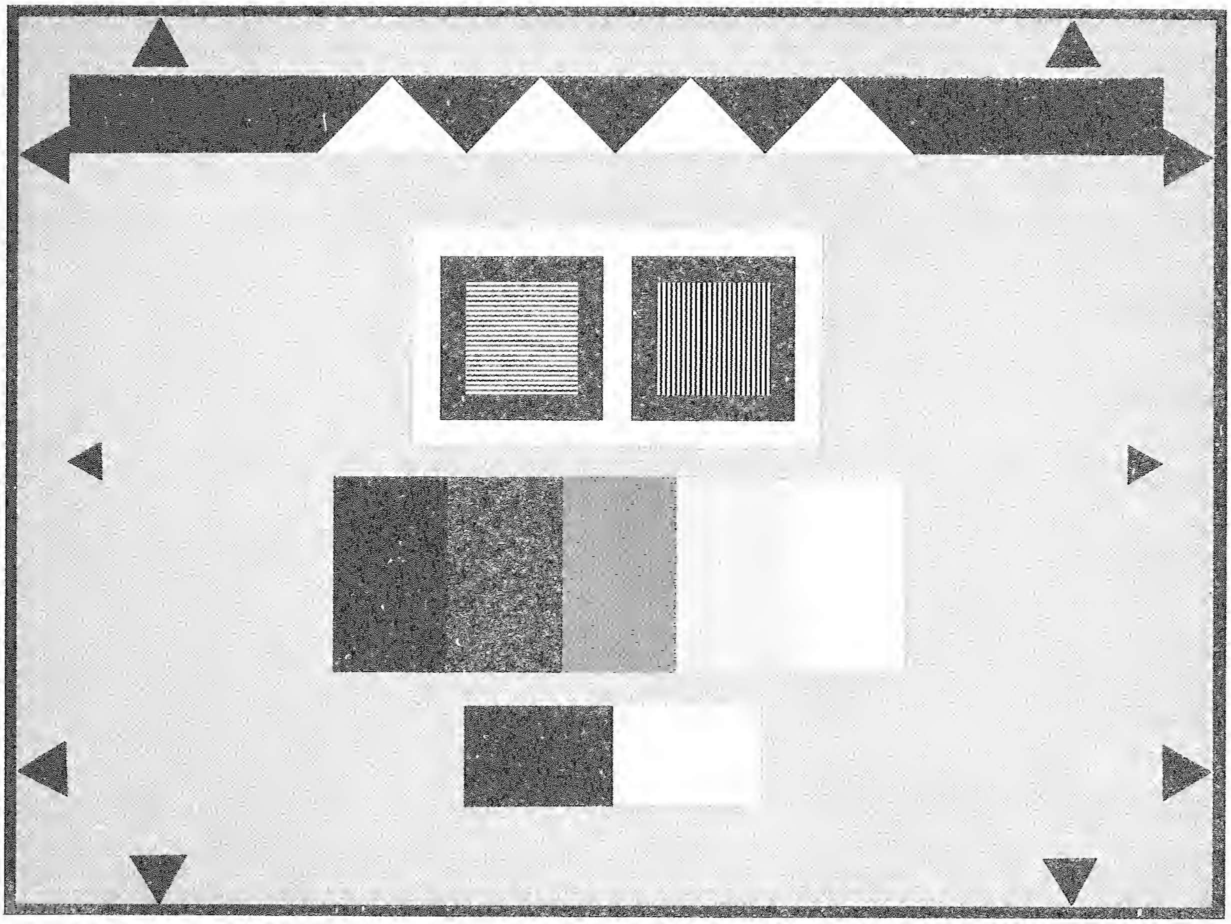

Fig. 1 - Test chart used for film steadiness measurements

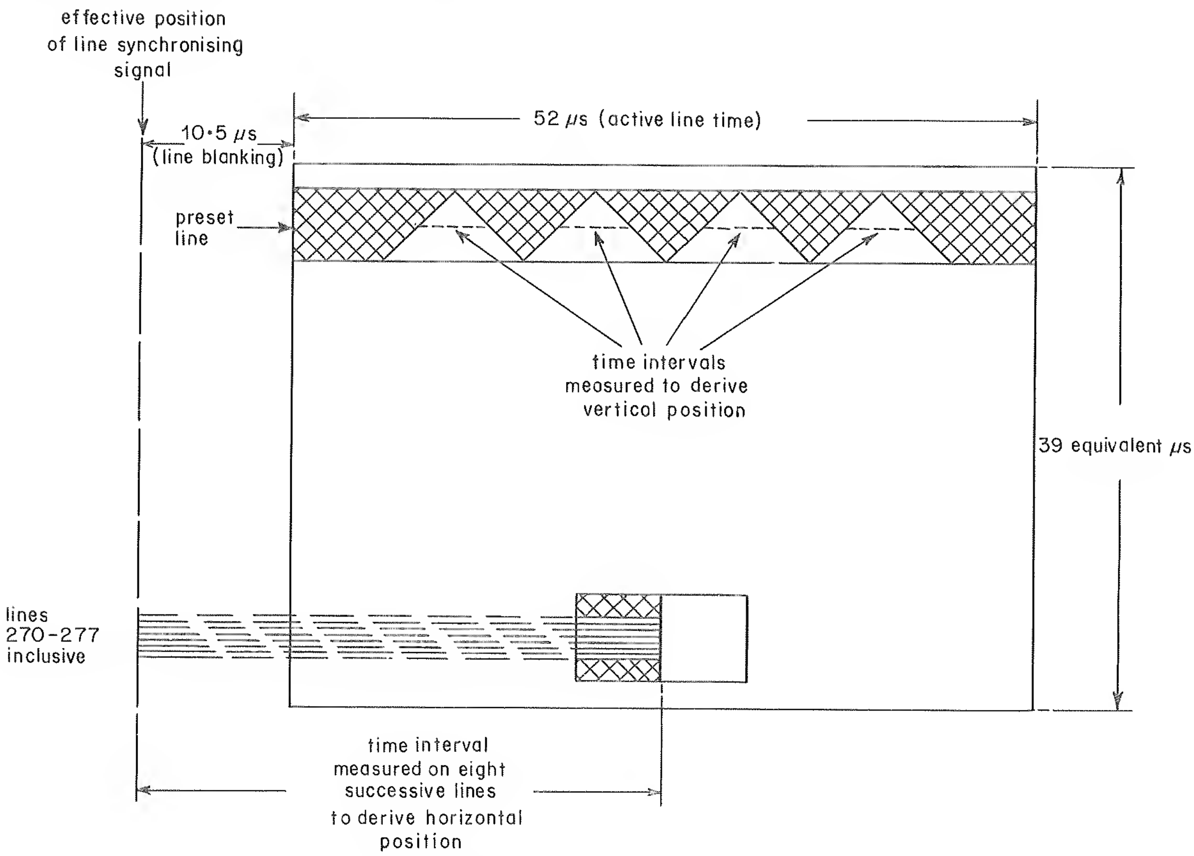

Fig. 2 - Essential features of the test chart showing the time intervals measured

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Part 1: The Measurement of Unsteadiness and Prediction of Subjective Impairment

Summary

Measurements of the overall steadiness of television film reproduction have shown that the error distribution is often not Gaussian. Since the frequency spectrum of the image displacement (regarding the latter as a function of time) can vary considerably for different films, account must be taken of the relative subjective visibilities of the different frequency components of the unsteadiness. The subjective tests outlined in this report establish the relative visibilities of these components. In addition, a method has been devised for predicting, from a picture-by-picture measurement of positional errors, the overall subjective impairment which the positional errors will cause when the film is reproduced on television.

1. Introduction

It is known that the positional steadiness of pictures from 16 mm film, reproduced by television, is sometimes unsatisfactory. Such image unsteadiness is due to relative positional errors between successive displayed pictures. These errors have in the past been assumed to have a Gaussian distribution and the subjective impairment of the picture was assumed to be related to the quasi peak-to-peak displacement of the image,[1] where two or more sets of positional errors were involved, each set being normally distributed, the overall effect was calculated by adding variances. Thus the standard deviation of the overall errors was obtained by taking the square root of the sum of the separate mean-square values the latter having assumed relationships to the quasi peak-to-peak values.

Experience has shown, however, that the distribution of positional errors is often not Gaussian and, therefore, for an investigation into film unsteadiness a method was required for objectively measuring these non-Gaussian errors.

An investigation of unsteadiness is most easily broken into two parts, one part to determine the subjectively permissible amount of unsteadiness and the other part to determine the amounts, and the separate causes, of positional disturbances;[2] if any process involved in the film camera-to-telecine chain which contributes, significantly, to the overall unsteadiness can be isolated, efforts can be made to improve it. These two parts of the investigation were carried out concurrently.

Although this report deals with the subjective assessment of unsteadiness, it also includes general details of the measurement of unsteadiness using test films; the results of measurements made from the film of a test chart were used to recreate artificially a variable degree of unsteadiness in the pictures from a television camera, to produce a realistic simulation of film unsteadiness for subjective assessment.

Preliminary tests were also made to determine the relative sensitivity of observers to different frequencies of sinusoidal picture displacement.

2. Measurement technique

2.1. General

The measurement equipment operates upon the video output signal of a normal telecine channel and in this way the overall steadiness of the film camera-telecine chain can be evaluated. A special test chart, shown in Fig. 1, is used as the picture source for the film camera and either the original camera-negative or a print from it is reproduced in the telecine. The measurement equipment measures and records the horizontal and vertical image position of either the odd or even field of each television picture, and the change in the reproduced image position from frame to frame, referred to as unsteadiness, can then be evaluated. If the results are recorded digitally, using a paper tape punch, a computer may be used to facilitate further analysis. A graphical presentation of the image movement can also be obtained from the computer, or alternatively an analogue output can be fed to a suitable recording device.

2.2 Image position

The image position is determined by measuring the timing of transitions in the video waveform which correspond to certain edges on the test chart. The essential features of the chart are redrawn in Fig. 2 together with indications of the time intervals that are measured.

2.2.1 Horizontal displacement

To measure the horizontal image-position the time interval from the line synchronising signal (which is effectively a fixed distance to the left of the raster) to the central black-to-white transition near the bottom of the picture is measured during eight successive lines; the measurement of several time intervals permits the effect of noise on the timing of the transitions in the video signal to be reduced by averaging.

If the picture moves to the right or left by a distance equal to say p nanoseconds of line-scan then the time interval during each of the eight lines will increase or decrease by p nanoseconds and the total measured time-interval change will be $8\ p$ nanoseconds (assuming, justifiably, that horizontal picture movement is zero during the period of the eight lines).

2.2.2 Vertical displacement

To determine the vertical position of the image the width (measured in terms of line-scan time) of each of the four white triangles near the top of the chart is measured during a pre-selected line of the raster (see Fig. 2). The total width is then a function of the timing of eight video transitions and hence the effect of noise is again reduced.

If the picture moves up or down by a distance equivalent to q nanoseconds of line-scan then, since the sides of the triangles are inclined at 45° to the vertical the total change in time interval will be $8\ q$ nanoseconds.

2.3 Time measurement and scaling

Digital time-interval measurement is employed. A binary counter is allowed to count 30 MHz clock pulses for the duration of the time interval to be measured. Thus one count represents $1/(30 \times 10^6)$ sec = 33 ns; and as an image displacement horizontally or vertically equivalent to p or q ns of line scan causes the measured time interval to change by $8p$ or $8q$ ns the change in count will be $8p/(33)$ or $8q/(33)$ respectively.

Each time interval can, due to the quantising nature of the counter, give rise to a rounding error of ½ count, i.e. a maximum error of four counts when eight intervals are measured. For this reason the two least significant bits of the counter are ignored (i.e. the original count is effectively divided by four). Thus a horizontal displacement equivalent to p ns of line scan which originally gave rise to a change in count of $8p/(33)$ will cause a change in count of $2p/(33)$ at the equipment output. It follows that one count at the output is caused by an image movement equivalent to 16·7 nanoseconds of line scan.

The picture width is equivalent to the active line time, i.e. approximately 52 μs on the 525 or 625-line standard, and it follows that, with an aspect ratio of 4 to 3, the height is equivalent to 39 μs of line time. This means that one output count which represents 16·7 nanoseconds of line time, is equivalent to 0·0423% of the picture height. In the 16 mm format the frame height is 0·3 in so that one output represents a film displacement of $1{\cdot}269 \times 10^{-4}$ in (or $3{\cdot}22 \times 10^{-6}$ m).

2.4 Digital output

The digital output is recorded on "five-hole" punched paper tape and using plain binary code, each character (1 row of holes) can represent decimal numbers between 0 and 31. The binary counter is pre-set before each vertical or horizontal measurement and, after the measurement, the two least significant digits are ignored because of accumulated rounding errors, as described above, and the next five digits are punched. One character is used to indicate the vertical position, the next the horizontal position and a third character is then punched as a blank in order that the vertical and horizontal data may be separately identified. This set of three characters is punched in real time as the film is analysed, so that in order to record information for 25 pictures a second* the punch operates at 75 characters per second.

The centre of the counter output range is arranged (by varying the number to which the counter is preset and the number of the line used for vertical position measurement) to represent the mean image position. A movement upward or to the right causes the number punched to be greater than the centre value, and conversely for movements downward or to the left. As already discussed, the output quantum is 0·0423% of the picture height, so that the peak-to-peak displacement which can be recorded on 5 hole tape is 31 x ·0423 = 1·31% of picture height.

This has proved just sufficient to cope with the worst encountered cases of unsteadiness. Fig. 3 shows a section of the punched tape with the corresponding image position represented graphically alongside.

2.5 Analogue output

An analogue output is derived at the same time that the punched tape is punched, by converting the digital output of the counter to analogue form and storing the analogue level in one of two sample-and-hold circuits; one sample-and-hold is used for vertical information, the other for horizontal, and each provides a signal which changes once per picture (i.e. once per film frame). A meter with high mechanical inertia, when fed with one of these outputs, indicates the mean picture position in the relevant direction and this indication is used to adjust the counter for the horizontal and vertical output in turn, so that the mean image positions correspond to the centre of the range of the punch. If a real time plot of image position is required the analogue signals can be fed to a two channel recorder capable of responding to a maximum frequency of 12·5 Hz.

3. Simulation of image unsteadiness

The test films used to analyse practical types of unsteadiness are not suitable for use in direct subjective assessments, because the picture is a test chart. It is possible however to use the measured unsteadiness of these test films to simulate the image unsteadiness of the original film on a television camera picture: this allows the scene content to be varied.

*This is the film frame rate used for television on the 625-line, 50-field system.

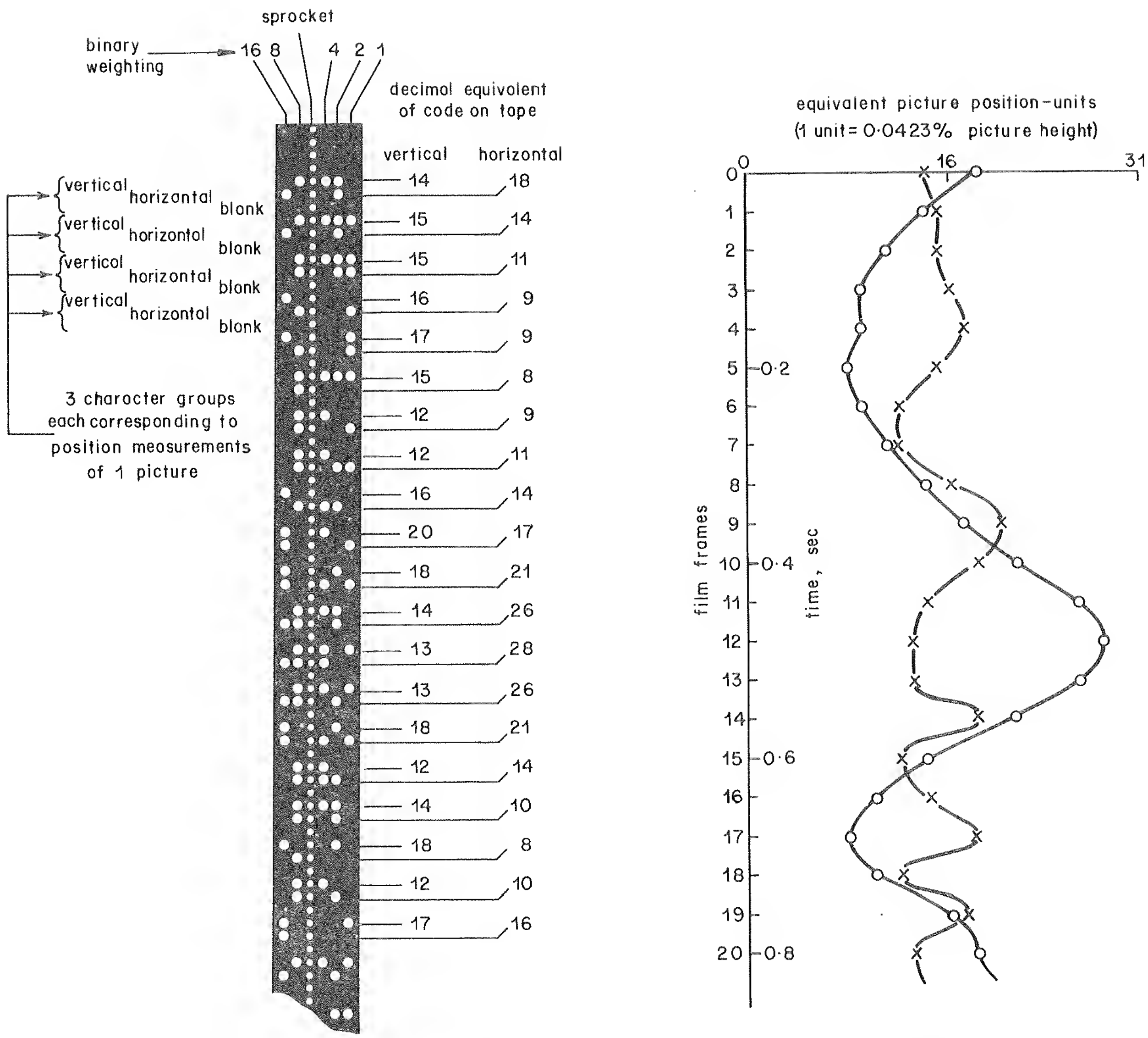

Fig. 3 - Punched tape with graphical representation of corresponding image position

key: x — vertical o — horizontal

The simulation is achieved by "reading" a punched tape produced from a test film and converting the resulting digital signals to analogue form for application to the camera scan centring circuits. In principle it would be possible to use the analogue outputs of the measuring equipment but this involves running the original test film in a telecine machine whilst performing the tests; this is less convenient than using a tape reader. A more important advantage in the use of punched tape is that exactly the same data is used in both the computation and the subjective test; thus the quantising noise which is added to the measurements is also taken into account in the assessment of subjective impairment.

Each character on the tape is read and the digital signal is converted to analogue form and stored in a sample-and-hold circuit for the vertical or horizontal signal, as appropriate. Synchronisation of the tape is achieved by ensuring that the blank which appears in each set of three characters occurs during the camera field-interval preceding each odd field. The output level of each sample-and-hold circuit changes once per picture and since these changes occur during active picture intervals the analogue signals are re-sampled during the field interval preceding each odd field. This ensures that the position of the camera picture remains fixed during the active picture period.

In order that the reproduced level of unsteadiness may be varied, the two re-sampled analogue signals are passed through switched attenuators before application to the camera scan centring systems.

3.1 Calibration

To calibrate the equipment a steadiness test chart is placed in front of the camera and the displacement of the reproduced image is measured by the steadiness measuring equipment. The simulation apparatus is arranged, with a test data tape, to alternate the picture between two positions, maintaining each position for a few seconds. The image displacement can then be measured by a suitable meter connected to an analogue output of the measuring equipment. In this way a preset adjustment can be set so that the magnitude of the displacement corresponds to the data on the test tape.

4. Initial subjective tests – sinusoidal disturbances

4.1 Object of the tests

The first series of subjective tests was carried out to determine the sensitivity of observers to sinusoidal picture position – disturbances of various frequencies. It was hoped that a generalised relative response frequency characteristic could be derived which would apply with reasonable accuracy to all cases of unsteadiness. If this proved successful it was proposed to use this characteristic to "weight" the spectral components of any measured practical unsteadiness and then to evaluate the r.m.s. value of the modified spectrum to provide, hopefully, an assessment of the subjective impairment.

4.2 Parameters

In practical cases of film unsteadiness the position of each film frame (2 television fields) remains unchanged and for this reason the sine waves used to disturb the picture were sampled on alternate television fields. The resulting sampling rate of 25 per second set the upper frequency-limit of the disturbance to 12·5 Hz (i.e. a period corresponding to two film frames). The lowest frequency of disturbance used in the tests corresponded to a period of 80 frames. This represents the range of frequencies which can occur in practical cases of unsteadiness.

To suit the simulation apparatus the samples were recorded on punched tape in digital form. Conversion to digital form involves quantising errors but, with five-hole punched-tape, thirty-two levels are available and by making the peak-to-peak variation of the sine wave cover most of this range (30 quanta p-p) the quantising noise is reduced to an acceptable proportion. Moreover, if increased accuracy is required, account may be taken of the quantising errors by submitting the data tape to computer analysis in a way similar to that used for practical cases of unsteadiness (see Section 5). The switched attenuators were used to vary the reproduced level of unsteadiness.

About 20 skilled observers were asked to grade disturbances of various amplitudes and frequencies, according to the EBU Impairment Scale shown in Table 1.

TABLE 1

EBU Impairment Scale

Grade	
1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

Tests were carried out both for still scenes and for scenes where moving objects covered about half the picture area; in each case the effects of disturbances in the vertical and horizontal direction were separately assessed. Tests with the whole picture content moving, e.g. due to panning, tilting or zooming to follow a moving subject, were not pursued when it became apparent that this condition could mask even severe cases of unsteadiness.

Each "disturbed" picture was displayed for ten seconds and, in between, a steady "reference" picture was displayed for about the same period. The use of the reference picture provided an analogy to the situation where unsteady film inserts appear in a programme mainly comprised of steady television camera pictures. It also prevented the observers gradually becoming accustomed to unsteadiness, as one might for a programme composed entirely of film pictures. It thus prevented any severe drift in the grading assessment for a given test condition as the tests proceeded.

4.3 Results

4.3.1 Still scene

The results of the still scene tests are shown plotted in Fig. 4. In each case, the ordinate is the mean grade for all the observers participating in the test, and is plotted against the peak-to-peak magnitude *(d)* of the disturbance, measured as a percentage of picture height. Each curve applies to one frequency of disturbance and is labelled according to the period, in frames, of the disturbing sine wave.

It can be seen from a comparison of Figs. 4*(a)* and 4*(b)* that horizontal and vertical disturbances of a still picture produce roughly similar results; as a consequence the results illustrated in Figs. 4*(a)* and 4*(b)* were combined to produce the curves shown in Fig. 4*(c)*. The curves of Fig. 4*(c)* were used to produce Fig. 5, which gives an estimate of the magnitude of a sinusoidal disturbance causing a given mean value of impairment, shown as a function of the period. It will be seen that disturbing signals having a longer period can generally be larger in magnitude for the same impairment; this indicates that observers have a reduced sensitivity to longer period (lower frequency) disturbances.

It was useful, at this stage, to develop curves of relative observer sensitivity plotted against disturbing sine wave frequency or period. These curves, which correspond to the curves in Figs. 5 appear as the solid lines in Fig. 6. The axes of Fig. 6 are logarithmic and the relative sensitivity, S, has been evaluated with respect to a peak-to-peak disturbance of 0·1% picture height and is expressed in decibels according to the relationship:

$$S = -20 \log_{10} 10\,d \quad \text{(dB)}$$

where d, the peak-to-peak magnitude of the disturbance, is measured as a percentage of the picture height.

4.3.2. Moving Scene

It was found that when a scene contained moving objects the assessments were rather erratic and that in particular any given disturbance was less objectionable. This is because moving objects tend to distract the observer and make the unsteadiness less visible. It will be shown

(see Fig. 9) that when there are moving objects covering about half the picture area the grading of a given disturbance is improved by between 0·75 and 0·9 grade, and for a given grade the disturbance may be about 3 dB larger in amplitude.

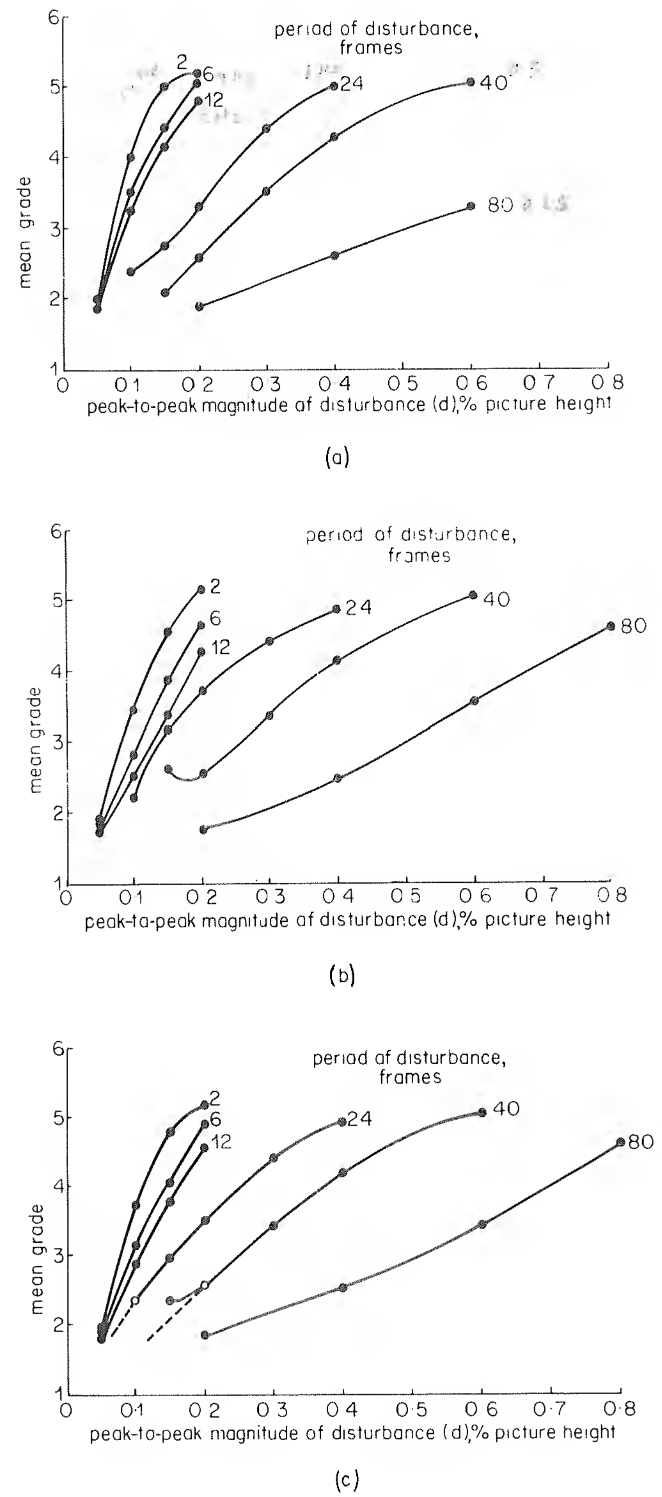

Fig. 4 - Responses of observers to various sinusoidal disturbances in the reproduction of a still scene

(a) horizontal disturbance *(b)* vertical disturbance
(c) horizontal or vertical disturbance (average of *(a)* and *(b)*)

The preliminary result curves are not shown but the relative sensitivity curves, which correspond to Fig. 6 for the still scene tests, appear in Fig. 7.

4.4 Picture unsteadiness weighting curve

For still scenes (Fig. 6) it can be seen that the frequency characteristics for each grade are broadly similar. It follows that it should be possible to adopt an arbitrarily defined characteristic which may be applied, with reasonable accuracy, to all grades. For scenes with moving objects (Fig. 7) the curves are less regular, but it will be shown that application of the same arbitrary characteristic is not likely to produce unreasonable errors.

The proposed picture unsteadiness weighting curve may be described as that exhibited by the response of a high pass C.R. circuit, having a time constant of 85 ms, as shown in Fig. 8. Such a circuit has its 3 dB point at 1·88 Hz, and the frequency characteristic is shown by the dotted curves in Fig. 6.

These curves have been positioned with respect to the corresponding experimental results to minimise the maximum error (i.e. spacing of the weighting curve from the true curve in dB) arising from use of the curve instead of the subjective results.

The relative position of the dotted curves on the sensitivity scale gives a measure of the relative disturbance required for different grades at a given frequency of disturbance. This relationship is illustrated by Fig. 9 and the maximum error margin arising from the use of the weighting curve is shown by the shaded area. A curve for moving scenes with its error margin is also shown.

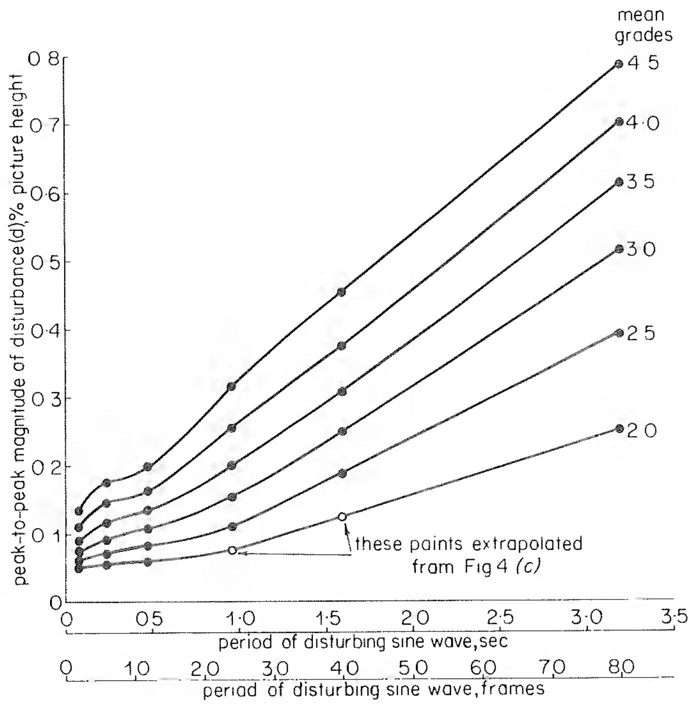

Fig. 5 - Variation of the magnitude of a sinusoidal disturbance producing a given mean impairment of a still scene, as a function of its period

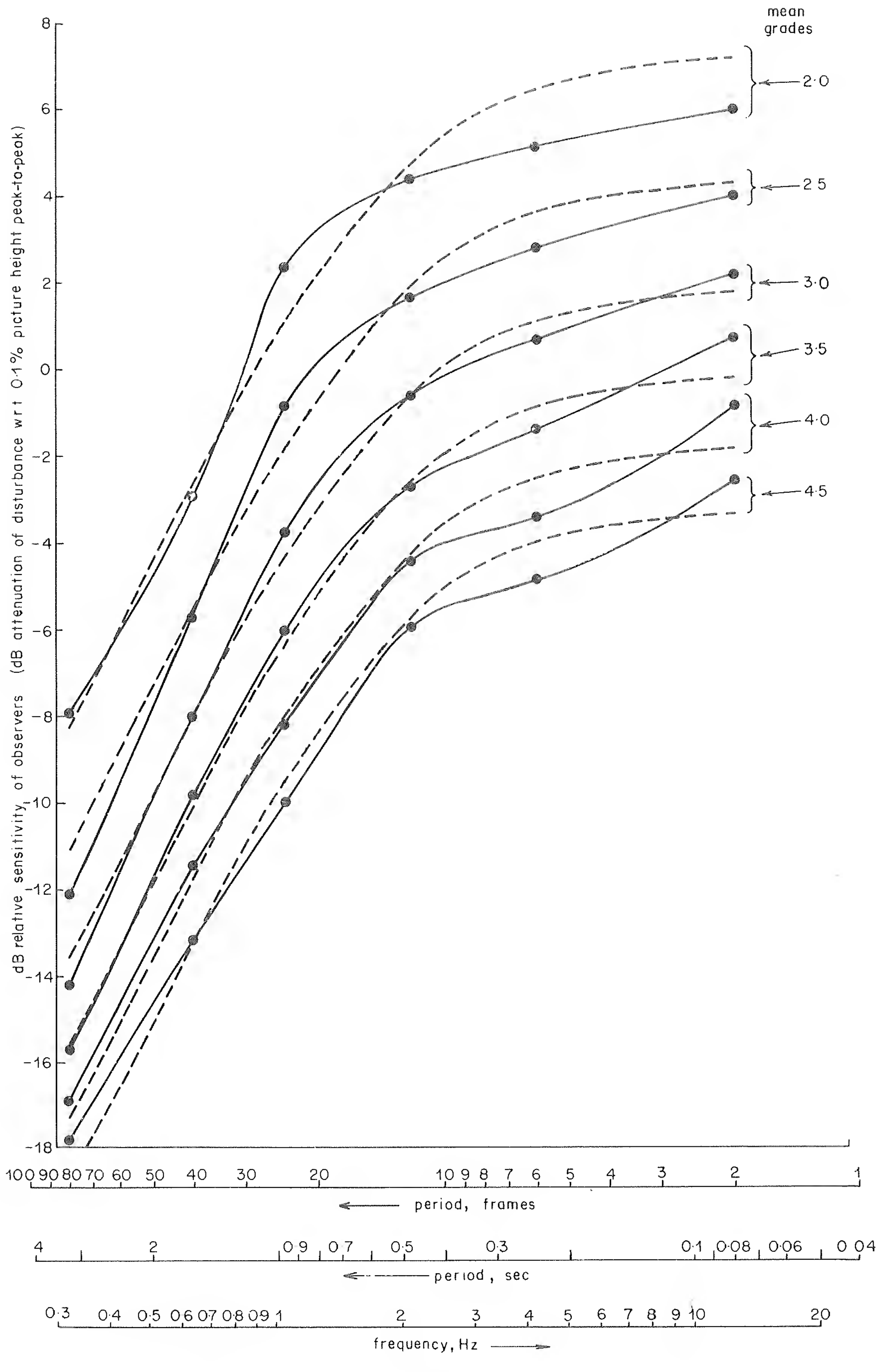

Fig. 6 - Relative response frequency curves for sinusoidal disturbances to still scenes

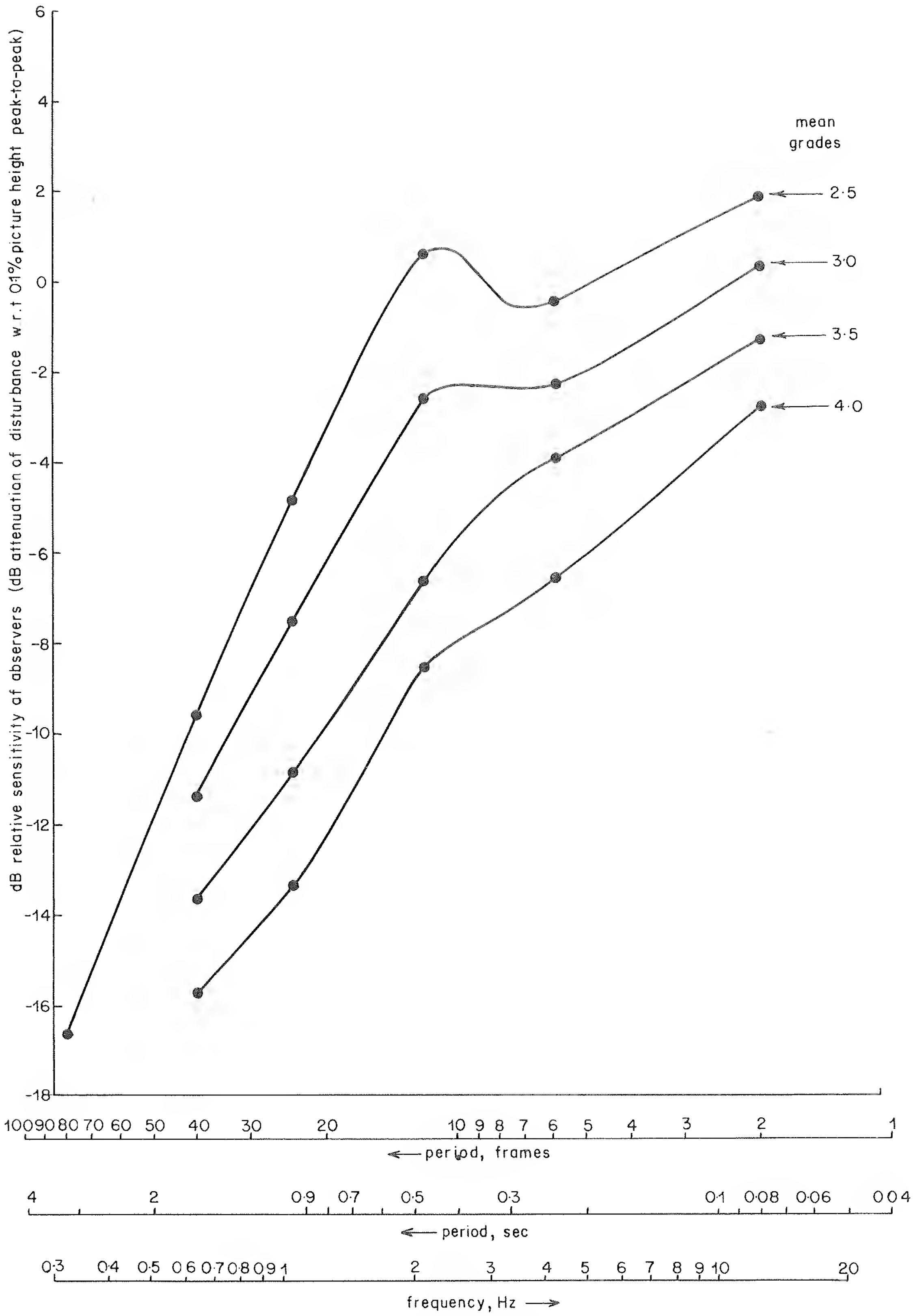

Fig. 7 - Relative response frequency curves for sinusoidal disturbances to scenes with about half of the picture area covered by moving objects

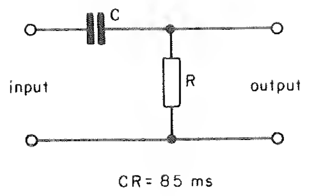

Fig. 8 - Circuit which has a frequency characteristic which resembles the curves in Figs. 6 and 7

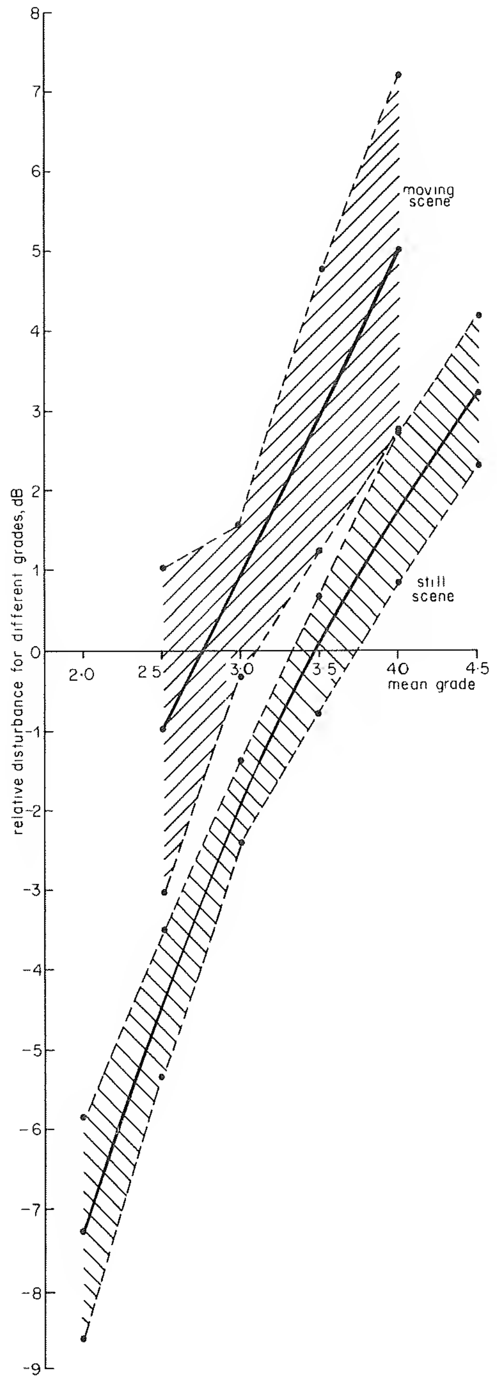

Fig. 9 - Relative disturbance for different grades. The shaded areas indicate the error which may result from the use of the circuit of Fig. 8 to define the responses shown in Figs. 6 and 7

4.5 Errors

In the assessment of practical cases of film unsteadiness the most critical case, that of still scenes, will probably be of primary interest and the acceptance level will be about 3 (definitely perceptible but not disturbing).

Under this condition the maximum error arising from the use of the weighting curve to define the relative sensitivity of observers to different frequencies amounts to only 0·15 grade. This error increases for other grades to a maximum for still scenes of 0·3 grade. With moving objects in a scene the errors caused by using the weighting characteristic are somewhat larger, up to 0·6 grade, but even this is thought to provide sufficient accuracy for useful analytical assessment of subjective impairment.

5. Analytical assessment of practical cases of unsteadiness

As described in Section 2 the measurement equipment measures and records the horizontal and vertical position of each film frame. The horizontal and vertical measurements may each be considered as a series of samples which depict a waveform, and the punched tape output from the measuring equipment may be interpreted by a computer to produce representations of these waveforms; some typical examples are shown in Fig. 10.

The waveforms, in sample form, can also be Fourier analysed by the computer to determine their spectral characteristics and in this way any predominant cyclic components of unsteadiness can easily be recognised. Once the frequency of any predominant component is known, steps may be taken to determine and eliminate the cause. To do this a knowledge is required of all the possible cyclic components which can be produced by each piece of equipment involved in the film process, and an analysis of the mechanics of the various pieces of equipment has shown that very few such components are possible. Moreover a given component is generally found to relate to a specific piece of equipment.

The fundamental frequency for the Fourier analysis should be carefully chosen so that the above-mentioned cyclic components will be exact harmonics. Furthermore, any disturbances at, or below, the fundamental frequency should be of a sufficiently low frequency that even if an amplitude variation at this frequency covers the entire measurement range the reduced subjective sensitivity will render it imperceptible. A fundamental with a period of 240 frames (i.e. a frequency of 25/(240) or 0·1042 Hz at the television frame rate of 25 per second) is used since it satisfies both conditions. The harmonic number n of any component is then given by:

$$n = 240/P$$

where P is the period of the component in frames.

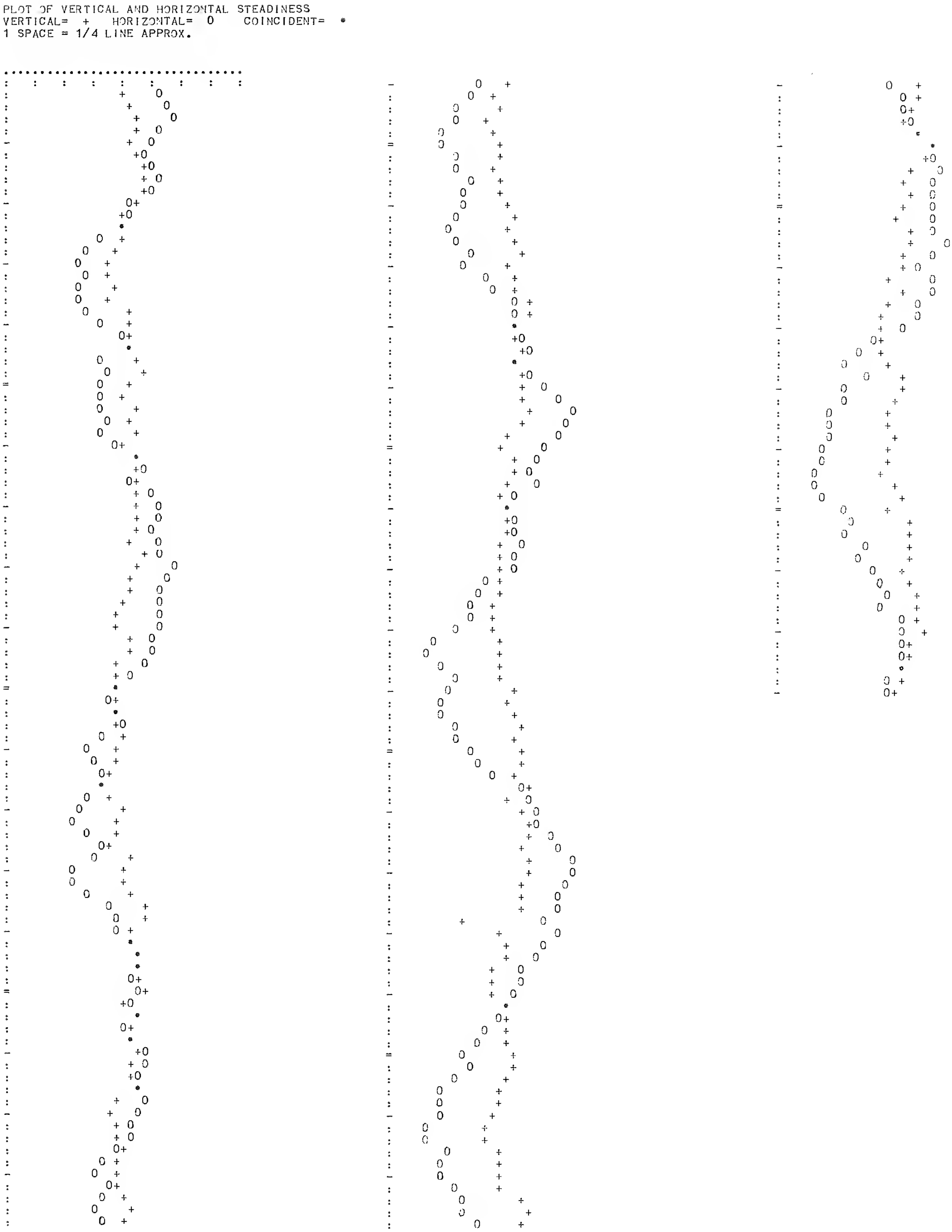

Fig. 10 - Computer presentation of typical unsteadiness waveforms

Since the complex waveforms representing horizontal and vertical unsteadiness are each constructed from one sample per frame, 240 samples of the waveform are used by the Fourier analysis programme. This requires that about ten seconds of continuous measurement be made and also sets the minimum length for the test film, which is conveniently equal to the lower limit of loop length which can be run in the telecine machine used for analysis. (Each test film is run as a loop to facilitate setting up the measuring equipment: the 240 frame block of results analysed is chosen to avoid the splice.)

The resulting Fourier analysis appears as a line spectrum with 120 harmonic components at intervals of 0·1042 Hz. The highest frequency component corresponds to 12·5 Hz, i.e. half the sampling frequency. Figs. 11*(a)* and *(b)* show computer print-outs of Fourier analyses which correspond to the waveforms shown in Fig. 10. The analysis of the horizontal unsteadiness (Fig. 11*(a)*) has a very predominant component with a 40-frame period (harmonic number n = 6) which is caused by a continuous motion contact printer which has 40 teeth on its main sprocket wheel. For the vertical analysis (Fig. 11*(b)*) this component is less predominant. The relatively uniform "background" spectrum in each case indicates the presence of random errors.

5.1 Weighted r.m.s. value and weighted power spectrum

This section adopts a method of using the picture unsteadiness response characteristic defined under Section 4.4; the accuracy of this method is subsequently verified by the second series of subjective tests described in Section 6.

Although it identifies predominant components the Fourier amplitude spectrum does not correctly indicate the relative subjective importance of the components, since as shown above the lower frequency components are subjectively more tolerable than high frequency components of the same amplitude. The spectral components are therefore modified by the picture unsteadiness weighting characteristic.

FUNDAMENTAL = 0.1042 HZ.
FOURIER HARMONIC COMPONENTS
1 SPACE = 0.0042% PK-PK

NO.	PK.AMP.	NO.	PK.AMP.
1	0.38	61	0.18
2	1.33	62	0.16
3	0.69	63	0.07
4	0.57	64	0.21
5	0.84	65	0.16
6	6.39	66	0.03
7	1.40	67	0.08
8	0.70	68	0.13
9	0.18	69	0.11
10	0.11	70	0.24
11	0.37	71	0.13
12	0.06	72	0.08
13	0.71	73	0.16
14	0.60	74	0.17
15	0.39	75	0.07
16	0.19	76	0.05
17	0.33	77	0.15
18	0.34	78	0.08
19	0.47	79	0.13
20	0.23	80	0.07
21	0.35	81	0.02
22	0.13	82	0.07
23	0.53	83	0.06
24	0.47	84	0.12
25	0.13	85	0.03
26	0.36	86	0.11
27	0.19	87	0.02
28	0.29	88	0.05
29	0.29	89	0.08
30	0.18	90	0.02
31	0.06	91	0.14
32	0.20	92	0.05
33	0.02	93	0.07
34	0.12	94	0.09
35	0.14	95	0.06
36	0.17	96	0.07
37	0.18	97	0.05
38	0.32	98	0.11
39	0.12	99	0.05
40	0.27	100	0.07
41	0.27	101	0.06
42	0.24	102	0.10
43	0.25	103	0.02
44	0.28	104	0.15
45	0.27	105	0.03
46	0.07	106	0.10
47	0.33	107	0.10
48	0.11	108	0.05
49	0.06	109	0.17
50	0.06	110	0.01
51	0.26	111	0.14
52	0.25	112	0.14
53	0.29	113	0.05
54	0.03	114	0.12
55	0.09	115	0.13
56	0.08	116	0.08
57	0.04	117	0.07
58	0.01	118	0.04
59	0.13	119	0.15
60	0.14	120	0.02

(a)

Fig. 11

Now it would seem reasonable to determine the combined subjective effect of the modified components by evaluating the overall r.m.s. value and since the components have been modified or weighted by a frequency characteristic this will be a "weighted r.m.s. value".

The picture unsteadiness weighting characteristic may be expressed mathematically as a function of frequency.

p.u.w.c. (amplitude response ratio) = $1/[1 + (1{\cdot}88/f)^2]^{1/2}$

The Fourier amplitude spectrum can be expressed as

$$a_1 \sin(\omega t + \phi_1) + a_2 \sin(2\omega t + \phi_2) + \ldots + $$
$$+ a_{120} \sin(120\omega t + \phi_{120})$$

If n is the harmonic number, then for a fundamental frequency of 0·1042 Hz

$$f = 0{\cdot}1042\ n$$

Each spectral component when weighted by the p.u.w.c. will become

Then weighted r.m.s. = $\left(\sum_{n=1}^{120} \tfrac{1}{2} b_n^2\right)^{1/2}$

The terms $\tfrac{1}{2}b_n^2$ for n = 1 → 120 plotted against harmonic number will produce a weighted power spectrum, which indicates the relative contribution of the components to the weighted r.m.s. and thus provides an indication of their relative subjective importance.

5.2 Combination of horizontal and vertical disturbances

The above process of Fourier analysis, weighting, and evaluation of the weighted r.m.s. is applied independently to horizontal and vertical disturbances and a method is required for evaluating their combined effects.

There may or may not be any correlation between the disturbances. For any disturbances or component parts, which are completely correlated a diagonal picture movement will result and the amplitude of this will be the root of the sum of the squares of the two components.

FUNDAMENTAL = 0.1042 HZ.
FOURIER HARMONIC COMPONENTS
1 SPACE = 0.0042% PK-PK

NO.	PK.AMP.	NO.	PK.AMP.
1	0.36	61	0.09
2	0.27	62	0.09
3	0.12	63	0.08
4	0.25	64	0.09
5	0.10	65	0.10
6	1.60	66	0.26
7	0.18	67	0.06
8	0.16	68	0.13
9	0.17	69	0.10
10	0.20	70	0.04
11	0.23	71	0.05
12	0.38	72	0.15
13	0.29	73	0.08
14	0.35	74	0.12
15	0.09	75	0.04
16	0.47	76	0.11
17	0.49	77	0.04
18	0.23	78	0.08
19	0.17	79	0.17
20	0.16	80	0.12
21	0.17	81	0.04
22	0.12	82	0.12
23	0.17	83	0.01
24	0.09	84	0.12
25	0.23	85	0.18
26	0.25	86	0.06
27	0.07	87	0.13
28	0.04	88	0.04
29	0.07	89	0.06
30	0.02	90	0.09
31	0.05	91	0.04
32	0.23	92	0.16
33	0.04	93	0.14
34	0.10	94	0.07
35	0.12	95	0.16
36	0.35	96	0.07
37	0.11	97	0.16
38	0.09	98	0.09
39	0.03	99	0.13
40	0.17	100	0.04
41	0.12	101	0.07
42	0.16	102	0.11
43	0.06	103	0.08
44	0.12	104	0.01
45	0.13	105	0.03
46	0.09	106	0.08
47	0.15	107	0.09
48	0.10	108	0.07
49	0.20	109	0.12
50	0.23	110	0.09
51	0.05	111	0.08
52	0.10	112	0.05
53	0.14	113	0.07
54	0.26	114	0.08
55	0.15	115	0.06
56	0.10	116	0.14
57	0.04	117	0.13
58	0.09	118	0.07
59	0.27	119	0.08
60	0.22	120	0.23

(b)

Fig. 11 - Computer printout of Fourier analysis of the waveforms in Fig. 10

(a) horizontal unsteadiness *(b)* vertical unsteadiness

Alternatively for any disturbances which are not correlated the method of addition of two r.m.s. values is also to take the root of the sum of the squares. It follows that this method will be equally applicable whether or not there is any correlation between the horizontal and vertical disturbances.

Therefore

$$(\text{overall weighted r.m.s.}) = [(\text{horizontal weighted r.m.s.})^2 + (\text{vertical weighted r.m.s.})^2]^{1/2}$$

5.3 Addition of two separate errors

It may be necessary in the investigation of the unsteadiness of a complete system, to add the effect of two or more disturbances occurring on a common axis in different parts of the film camera-telecine chain. Since these errors cannot in principle be correlated, they may also be added by the root sum square method so that for separate errors A, B, C ...

$$(\text{overall weighted r.m.s.}) = [(\text{weighted r.m.s. A})^2 + (\text{weighted r.m.s. B})^2 + (\text{weighted r.m.s. C})^2 + \ldots]^{1/2}$$

5.4 Twelve loop averaging

The accuracy obtained by a single measurement of a loop of film is limited because:

(1) A quantising error can occur in the measurement of the position of each frame

(2) The unsteadiness caused by the telecine machine will be included in the measurement

The twelve loop averaging technique considerably reduces these errors, some components being completely eliminated.

If several consecutive measurements are taken of the same loop of film and the errors recorded for each specific frame are average over, say, N measurements, the quantising errors will, statistically, be reduced by a factor of $\sqrt{N}$.

Also, if the loop length is arranged so that each time a measurement is made a particular frame in the loop coincides with a different part of the telecine mechanism (i.e. a different tooth on each sprocket wheel and a different claw in the gate), and if enough measurements are made so that every sprocket tooth meets every film frame an integral number of times, then any cyclic errors due to the mechanism can be eliminated. Since the telecine machine used has 12 teeth on its sprocket wheels, twelve measurements are made. Each frame then coincides once with each sprocket tooth, and since there are two claws in the gate, each operating on alternate frames, each frame meets each gate claw six times.

The loop is made $12m \pm 1$ frames in length (where m is an integer) to achieve the required condition. Usually the initial length is 301 frames (reducing to 299, 289, 287, 277 frames if the splice breaks).

To identify the data for each specific film frame the twelve loop measurements must be made in a continuous recording (on punched tape) and the loop length in frames must be known. The average result for each of the 301 frames is evaluated by the computer and the position of the splice in the recording cycle found. For Fourier analysis a 240 frame block of results is chosen to avoid the splice, as for single loop measurements.

Cyclic components caused by the telecine with periods of 2, 3, 4, 6 or 12 frames will be eliminated from the result by the above process, while any such components present on the film will still be evaluated as required. The effect of quantising errors on the final result will be reduced by a factor of $\sqrt{12}$ and random telecine errors (which are assumed to have a Gaussian distribution) will be reduced by a factor of $\sqrt{12}$.

6. Second series of subjective tests — practical type of disturbance

6.1 Object of the tests

If it is to be of any practical use, an analytical assessment of subjective impairment must bear a fixed relationship to the mean grade produced from practical observations and the relationship must be independent of the spectral content of the disturbance. The second series of tests was devised to check the performance in this respect of the weighted r.m.s. value of unsteadiness. The tests were also arranged to check the validity of the root sum square method for the combination of horizontal and vertical weighted r.m.s. errors.

6.2. Method of testing

Practical steadiness measurements were available from about 80 strips of test film which had been acquired for the investigation into the steadiness attained by 16 mm film.[2] From these, twelve strips were selected as a representative sample in terms of the spectral content of the unsteadiness. The weighted r.m.s. unsteadiness values of the horizontal and vertical disturbances of each strip were found by computer from the punched tapes produced by the measurement equipment, and the exact sections of punched tapes used by the computer analysis were then used in the simulation apparatus to reproduce the unsteadiness on a television camera picture.

As the computer programme analyses the measurements from a block of 240 frames, the test length becomes just under 10 seconds (240 frames at 25 frames per second). A still scene was used as the picture source to obtain the most critical conditions for assessment and, as in the first series of tests, the tests were interspersed by a steady reference picture which was also displayed for about ten seconds.

A total of 24 observers in three groups were asked to grade various amplitudes of horizontal, vertical and combined horizontal and vertical disturbances for each test strip, according to the EBU scale shown in Table 1. Since

the observers were split into three groups, any slight errors in the application of individual tests would produce a reduced effect on the final average.

6.3 Results

Fig. 12 shows the resulting mean grades plotted against the reproduced amplitude of the weighted r.m.s. unsteadiness. This reproduced amplitude takes into account the scale factor imposed on the original measurements by the switched attenuators used to vary the amplitude. Also where applicable, the horizontal and vertical disturbances have been combined by the root sum square method proposed under Section 5.2.

Also shown in Fig. 12 is a curve derived from the predicted relationship, shown by Fig. 9, between relative disturbance and grade. The absolute level of disturbance has been arbitrarily scaled so that the average deviation of the points from the curve is a minimum. For the curve as shown, 72% of the points lie within 0·25 grade of the curve and all are within 0·75 grade.

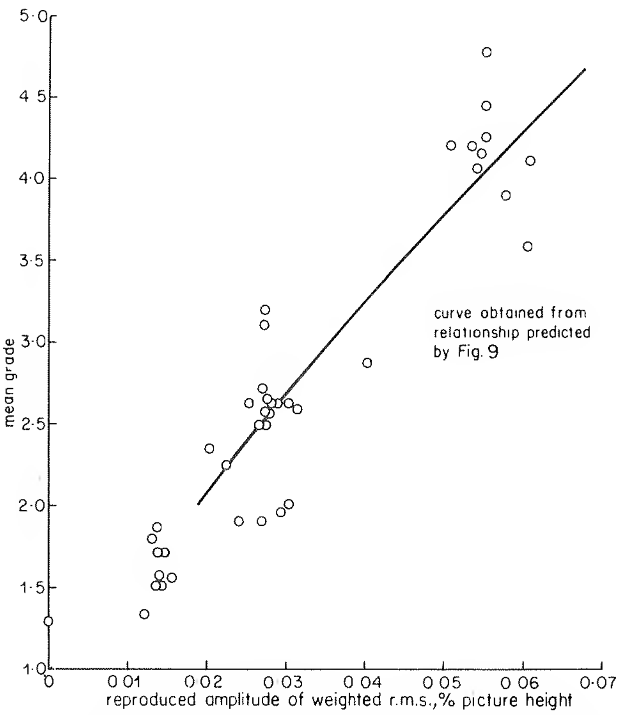

Fig. 12 - Relationship between mean grade and weighted r.m.s. unsteadiness for types of unsteadiness which occur in practice

The tests which gave rise to the points furthest from the curve were analysed for correlation with any various factors involved, which are listed below.

(1) Film sample for which unsteadiness was simulated

(2) Attenuator setting used

(3) Whether horizontal, vertical or combined hroizontal and vertical unsteadiness was displayed

(4) Direction of error.

It was noted that all the tests producing points significantly above the curve contained a horizontal component and all those producing points significantly below the curve contained a vertical component. The effects were not due to the film sample used or the attenuator settings and where both horizontal and vertical components were present, the direction of error is not controlled by their relative amplitudes. Since there is no direct correlation the method of assessment could not be improved to remove the errors and it can be concluded that the weighted r.m.s. value of unsteadiness may be used to predict the mean grade of subjective impairment to within 0·75 grade in all practical cases of film unsteadiness and that in 72% of cases the prediction will lie within 0·25 grade. It is also evident that the method of combining horizontal and vertical disturbances is valid.

7. Permissible limit of unsteadiness

As mentioned in Section 4.5 it seems reasonable that the acceptable limit of unsteadiness should correspond to a grade 3 subjective impairment — definitely perceptible but not disturbing — and it is now only necessary to define a value of weighted r.m.s. unsteadiness which corresponds to this grade. It should be noted however that this level will depend upon whether or not there are moving objects in the scene and also to a small extent upon the length of time for which the unsteady picture is displayed.

For the most critical case of no movement in the scene, Fig. 12 indicates that the weighted r.m.s. value for grade 3 is 0·035% picture height. (The results of the first series of tests with sinusoidal disturbances suggest that the value should be 0·028%, probably because the disturbances were sinusoidal and therefore more easily identified.) The sinusoidal tests showed that the disturbance can be about 3 dB greater when there is movement in the scene covering about half the picture area; this factor seems equally likely to apply to a complex disturbance.

It is therefore recommended that for acceptable steadiness of television pictures the weighted r.m.s. value of unsteadiness should not be greater than 0·035% picture height for critical scenes, and should be better than 0·045% (grade 3½ for a critical scene) for normal programme material.

8. Conclusions

Subjective tests have shown that the response of observers to different component frequencies of picture position disturbance is such that for a given amplitude of disturbance, lower frequency disturbances are less objectionable. Subsequently a picture unsteadiness response characteristic has been defined which may be used to weight the Fourier spectrum components of a disturbance and thence to deduce a weighted r.m.s. value of unsteadiness. It has then been shown that, for various types of unsteadiness occurring in practice, the weighted r.m.s. value bears a fixed relationship to the subjective impairment. In

this way a means has been provided of assessing film equipment performance by an analytical method using measurements made from test films.

This should greatly assist routine checks of equipment performance by eliminating the need for subjective observation.

9. References

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